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Search for Rare Decays of the K_L^0

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Abstract

We report on a search for the rare decays $K_L^0 \to \mu^\pm e^\mp$, $K_L^0 \to e^+e^-$, and $K_L^0 \to \pi^0 e^+ e^-$ at the Brookhaven AGS. Limits obtained for these processes are $BR(K_L^0 \to \mu^\pm e^\mp) < 1.9 \times 10^{-9}$, $BR(K_L^0 \to e^+e^-) < 1.2 \times 10^{-9}$, and $BR(K_L^0 \to \pi^0 e^+ e^-) < 3.2 \times 10^{-7}$.

In the standard SU(3) x SU(2) x U(1) model the decay $K_L^0 \to \mu^\pm e^\mp$ is forbidden by lepton generation number conservation. However, the standard model provides no insight into the number of generations or the mechanism of lepton generation number conservation. Many models that go beyond the standard model predict lepton generation number violation, and in particular the decay $K_L^0 \to \mu^\pm e^\mp$ [1]. The previous experimental limit for this process is $BR(K_L^0 \to \mu^\pm e^\mp) < 6 \times 10^{-6}$ [2].

The decays $K_L^0 \to e^+e^-$ and $K_L^0 \to \pi^0 e^+ e^-$ occur as a consequence of strangeness changing neutral currents and are highly suppressed in the standard model. The decay $K_L^0 \to e^+e^-$ is suppressed with respect to the observed rare decay $K_L^0 \to \mu^+\mu^-$ because of the small value of m_e/m_k. The process $K_L^0 \to e^+e^-$ is then particularly sensitive to new interactions proceeding through pseudoscalar currents. The previous experimental limit for this process is $BR(K_L^0 \to e^+e^-) < 2 \times 10^{-7}$ [2]. The decay $K_L^0 \to \pi^0 e^+ e^-$ through one photon exchange is a CP violating process. The branching ratio for a CP conserving decay transition through two virtual photons is expected to be below 10^{-11}. The decay $K_L^0 \to \pi^0 e^+ e^-$ is then an excellent window to search for light scalar particles that couple to e^+e^-. Furthermore, some non-standard models of CP invariance violation predict branching ratios higher than 3×10^{-11} [3]. The previous experimental limit for this process is $BR(K_L^0 \to \pi^0 e^+ e^-) < 2.3 \times 10^{-6}$ [2].

The experiment was performed in the A3 line of the Brookhaven AGS. A neutral beam was produced in the forward direction by the interactions of 24 Gev/c protons

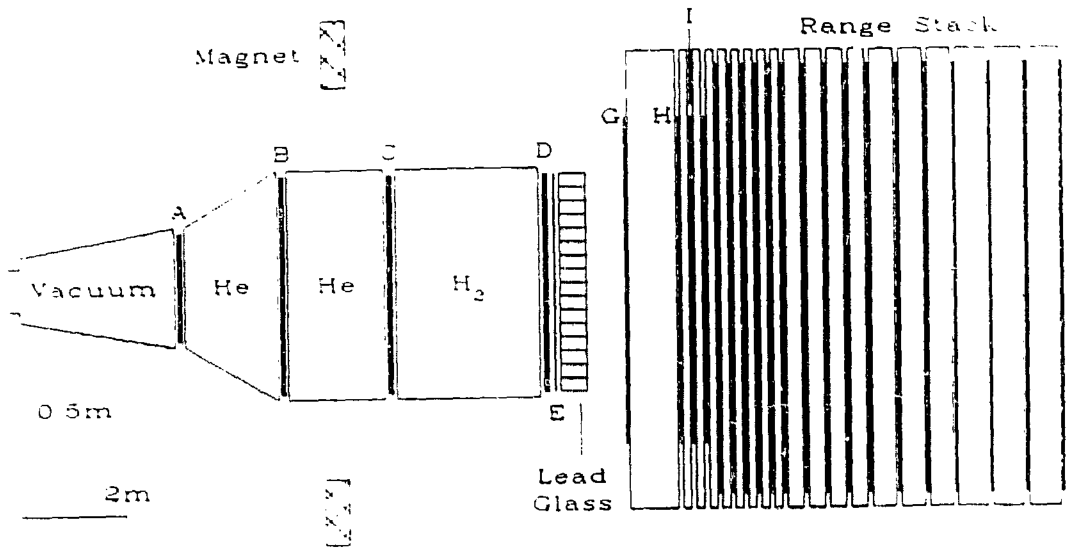

Figure 1: Plan view of the detector

with a copper target. Charged particles were swept away with a magnetic field, and gamma rays were attenuated by a lead plug. The 2.9 m long evacuated decay region began 7.5 m downstream of the target. The mean kaon momentum was about 7 Gev/c. A schematic representation of the detector is shown in Figure 1. The momenta of the charged particles from kaon decays were determined by a magnetic spectrometer made up of two upstream sets mini-drift chambers (labeled A and B), a magnet with a field integral of Δp = 220 Mev/c, and two downstream mini-drift chamber sets (labeled C and D). The maximum drift distance in these chambers was 3 mm. Electrons were identified by an atmospheric pressure hydrogen Cerenkov counter located between the C and D drift chambers, and a lead glass array downstream of the D chamber. The Cerenkov counter consisted of four cells and had an 8 Gev/c threshold for pions. The lead glass array was constructed of 244 blocks arranged in a 1 m x 1 m array with a central hole to pass the neutral beam. The energy resolution was determined to be $\sigma/E = 11\%/\sqrt{E}$. Muons were identified by their passage through a 1.0 m steel filter and their energy was measured by a range stack instrumented with scintillation counters. We accepted about 8×10^{11} protons per AGS pulse, which generated approximately 10^7 counts/m^2/sec in the detector. Further information on the detector may be found in Reference [4].

For the two body decay modes $K_L^0 \to \mu^\pm e^\mp$ and $K_L^0 \to e^+e^-$, the kinematically similar decay $K_L^0 \to \pi^+\pi^-$ served as a normalization and a measure of detector resolutions. We collected effectively 4×10^6 $\pi\pi$ decays. The events were required

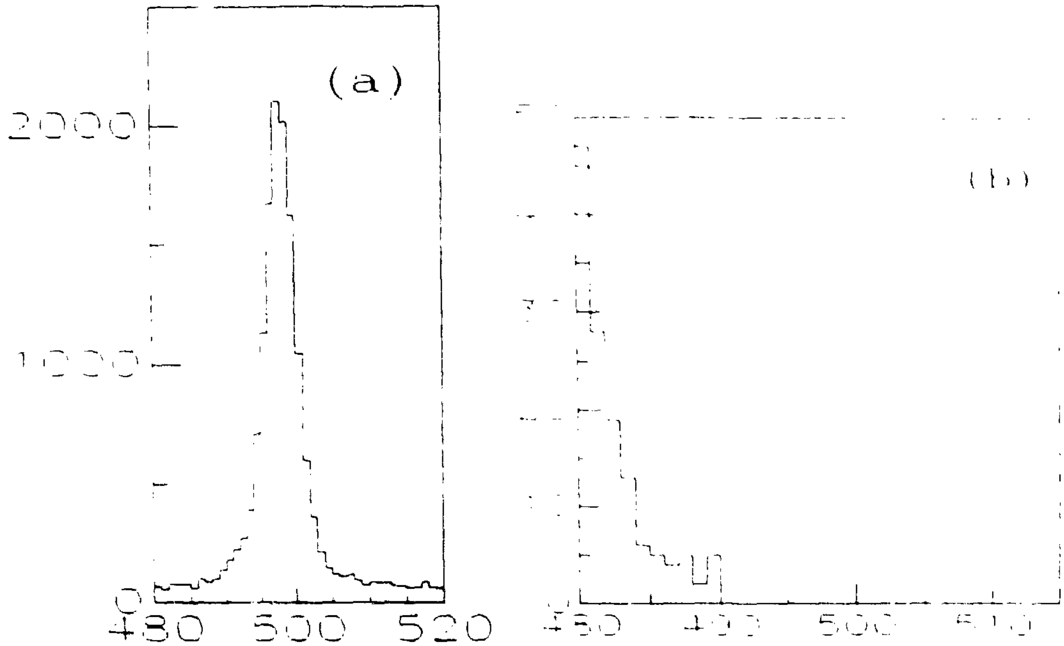

Figure 2: Invariant mass for (a) $K_L^0 \to \pi^+\pi^-$ and (b) $K_L^0 \to \mu^\pm e^\mp$

to pass cuts on track quality and distance of closest approach at the vertex. The effective mass distribution for events having an inbending geometry is shown in Fig. 2a. The mass resolution is $\sigma = 2.3$ Mev/c. Only inbending events were used in the μe analysis. The square of the angle (θ^2) between the total momentum vector of the charged products and the line joining the vertex with the target is an important parameter in defining a two body decay. Good $\pi\pi$ events satisfy $\theta^2 < 1.5\mathrm{mr}^2$.

The decay $K_L^0 \to \mu^+\mu^-$ served to verify our estimation of the sensitivity of the experiment. The constraints of kinematic reconstruction are important in searches for $K_L^0 \to \mu^\pm e^\mp$ and $K_L^0 \to \mu^+\mu^-$ to discriminate against backgrounds from $K_L^0 \to \pi\mu\nu$ and $K_L^0 \to \pi e\nu$ with the pion decaying to or being misidentified as a muon. We expect similar background distributions in the μe and $\mu\mu$ searches. Various cuts were applied to reduce backgrounds. In particular, the energy obtained from the muon range was required to be at least 70% of the momentum as measured in the magnetic spectrometer. After all cuts were imposed we find *eight* $\mu\mu$ events clustered within 1.8 σ of the K mass, with no nearby background. If we use the known $\pi\pi$ branching ratio, apply acceptance and other corrections, and use the world average [2] $BR(K_L^0 \to \mu^+\mu^-) = 9.1 \times 10^{-9}$, we would expect to observe *seven* events.

The same kinematic and muon identification requirements were made on the μe data. In addition, the electron energy as measured in the lead glass divided by the momentum measured in the spectrometer was required to be greater than 0.75. The invariant mass distribution for μe events which point back to the target within

1.5 mr^2 is shown in Fig. 2b. There are no events close to the K mass, with the nearest being 3.7 σ below the K mass. We thus find no events consistent with the decay $K_L^0 \rightarrow \mu^\pm e^\mp$. The single event sensitivity to the decay was determined to be 8.1×10^{-10}. The 90% confidence level upper limit is then $BR(K_L^0 \rightarrow \mu^\pm e^\mp) < 1.9 \times 10^{-9}$.

For the ee data we impose the same kinematic and electron identification cuts. Events with an outbending geometry have been included in the sample. We find no events consistent with $K_L^0 \rightarrow e^+e^-$. The nearest event with acceptable θ^2 is 25 Mev/c^2 below the K mass. The single event sensitivity to the decay was determined to be 5.2×10^{-10}. The 90% confidence level upper limit is then $BR(K_L^0 \rightarrow e^+e^-) < 1.2 \times 10^{-9}$.

For the three body decay mode $K_L^0 \rightarrow \pi^0 e^+ e^-$, the topologically similar decay $K_L^0 \rightarrow \pi^0\pi^+\pi^-$ serves to determine the normalization and a measure of mass resolutions. The charged particle tracks were required to pass cuts on track quality and distance of closest approach at the vertex. All events were required to have at least two gamma ray clusters in the lead glass besides the two charged track clusters. Only events with exactly one $\gamma\gamma$ combination within 30 Mev/c^2 of the mass were selected. If such $\gamma\gamma$ pairs are constrained to have the π^0 mass, the mass resolution for $K_L^0 \rightarrow \pi^0\pi^+\pi^-$ is $\sigma = 3.7$ Mev/c^2. Using this result, the mass resolution for $K_L^0 \rightarrow \pi^0 e^+ e^-$ is calculated to be $\sigma = 4.4$ Mev/c^2. The events are also constrained by the requirement that their total momentum vector reconstructed from charged and neutral products point back from the vertex to the target. For otherwise acceptable $K_L^0 \rightarrow \pi^0\pi^+\pi^-$ events, $\theta^2 < 10$mr^2. For the decay $K_L^0 \rightarrow \pi^0 e^+ e^-$ no events consistent with pointing to the target have been found. Because of our acceptance, the limit on $K_L^0 \rightarrow \pi^0 e^+ e^-$ is a strong function of e^+e^- effective mass. For a population of events distributed uniformly in the Dalitz plot, the 90% confidence level limit is $BR(K_L^0 \rightarrow \pi^0 e^+ e^-) < 3.2 \times 10^{-7}$.

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